Synthesis of 41,300 Drift Cards Released in Juan de Fuca Strait (1975-2002)

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[Editor's note: Figures 2-8 for Sauers et al appear at the end of this paper.]

Abstract

Drift cards have been used extensively in surface circulation, habitat, and environmental studies. Here we present a synthesis of five major drift card studies conducted in the Pacific Northwest over the last 25 years. A total of 41,300 cards were released from 155 sites, of which, 11,239 cards were reported by beachcombers. Inspection of the data suggests that Juan de Fuca Strait can be subdivided into at least four quadrants based on varying degrees of particle retention and dispersion. In this study, we use historical drift card data to examine the question of whether or not these quadrants function as semi-isolated domains and to explore the implications in the context of marine protected area network design. Floatable material originating from western Juan de Fuca Strait tends to move seaward, and there is preferential movement from the southern side of the Strait to the northern side, which we interpret as a moderate and asymmetric linkage between the two sides of that basin. Material originating from the eastern basin tends to remain within the region, and relatively strong and asymmetric linkages exist between the northern and southern sides of that basin.

Introduction

Surface ocean currents transport a variety of buoyant materials, including living organisms such as phytoplankton and larvae as well as surface-borne pollutants such as oil and plastic. These materials are continually being suspended, dispersed, deposited and re-suspended by surface currents along the world's shorelines. Dispersal processes have positive and negative effects on marine organisms and their habitats. While dispersal plays an important role in the survival of marine populations, it also provides a transport mechanism for water-borne pollutants.

Marine protected areas (MPAs) are designed to promote and restore biodiversity as well as protect marine life from threats such as destruction of coastal habitat and over exploitation. The design criteria for MPA networks of are currently under development (e.g., Roberts et al 2003), but it is generally agreed that an effective MPA must be self-sustaining and capable of supplying larvae to other protected and unprotected populations (Carr and Reed 1993; Ballantine 1997; Starr 1998). Therefore, both larval supply and the degree of linkage between sites play an important role in establishing effective MPA networks. Larval supply affects recruitment rates and, for populations limited by recruitment, helps sustain local populations. Linkages allow larval exchange between MPAs, augment population persistence and growth, as well as guard against losses due to stochastic processes (Klinger and Ebbesmeyer 2001).

Figure 1. A typical wooden drift card. Wooden and plastic, postcard-sized drift cards have been used.

Larvae of numerous species (e.g., rockfish, echinoderms, decapods) spend a significant period of time in the plankton (Strathmann 1987; Allison et al 1998). In nearshore areas, local and regional circulation patterns play important roles in larval recruitment. A variety of instruments (e.g., current meters, satellite-tracked drifters) are used to measure and describe circulation patterns. Practical constraints, however, limit use of these instruments in depths shallower than a few meters. Drift cards (Figure 1) offer one of the few practical alternatives to these sophisticated instruments for measuring advection and dispersion in the surface layer. Drift cards have proven to be an effective low-cost tool for the determination of near-surface flow as well as the identification of shoreline collection zones. For the purpose of this paper, collection zones are defined as shoreline segments that are likely to collect water-borne material due to their proximity to tidal eddies and other oceanographic features.

Drift cards have been used extensively in marine regions of the Pacific Northwest. Over the last 25 years, five major drift card studies have been performed in the region. In aggregate, more than 41,300 drift cards have been released from 155 sites in Juan de Fuca Strait and its approaches (Figure 2). Of the cards released, 11,239 cards were recovered and reported by beachcombers (Figure 3). The question is often asked about whether or not a bias of drift card recoveries exists based on population density. Ebbesmeyer and Coomes (1993) examined the coast mile by mile and found that peaks in drift card recoveries, in both passive and active studies, corresponded to sections of shorelines affected by tidal eddies. (Waldichuk 1958; Cox et al 1978; Pashinski and Charnell 1979; Cox et al 1980; Ebbesmeyer 1985; Ebbesmeyer et al 1991a; Ebbesmeyer et al 1995; Klinger and Ebbesmeyer 2001; Ebbesmeyer et al 2002).

Cursory inspection of the five major data sets and consideration of the general flow patterns in Juan de Fuca Strait (JF) (Cannon this session) suggested that the region could be subdivided into quadrants. Therefore, we combined the results of these five drift card studies to quantitatively examine the question of whether or not these quadrants function as hydrodynamically distinct domains.

Juan de Fuca Strait is a complex region bounded by the San Juan Archipelago to the north, Puget Sound to the south, and the Pacific Ocean to the west. The overall circulation of JF is representative of fjords in which the circulation is predominantly driven by tides, winds and fresher surface water flowing seaward overlying saline bottom water flowing landward (Lavelle et al 1991). Surface waters flow seaward at an approximate speed of 6 km/day (Pashinski and Charnell 1979), primarily driven by the Fraser River discharge and, to a smaller degree, drainage from the Skagit River and lower Puget Sound. Occasionally, flow reversals occur in JF due to periodic Pacific Ocean intrusions. These landward intrusions are often associated with winter storm events lasting approximately 1-10 days (Thomson 1981; Ebbesmeyer et al 1991b). Sills located at the north, south, and western entrances to the Eastern JF basin cause vigorous mixing of surface and bottom waters (Ebbesmeyer and Barnes 1980).

In JF, the complex bathymetry and adjacent landmasses promote mixing and cause the formation of numerous horizontally circulating eddies. The generation of eddies behind headlands and spits, commonly associated with oscillatory tidal currents, has been widely observed (Signell and Geyer 1991). Headland eddies affect the transport of dissolved and suspended material by furnishing an important mechanism for the dispersal of buoyant particles (Geyer and Signell 1990; Ebbesmeyer et al 1991).

Methods

Data from the five largest drift card studies performed in JF were combined. These five studies account for 90% of all cards released in the region. In chronological order, the first study was conducted by the Pacific Marine Environmental Laboratory (PMEL) from 1976 to 1978 as a part of the Puget Sound Drift Program (Pashinski and Charnell 1979). The second and third were conducted by Evans-Hamilton, Inc. in 1980 and 1992, respectively, as oil spill trajectory studies (Cox et al 1980; Ebbesmeyer et al 1995). The fourth study was conducted by Klinger for purposes of exploring MPA design (Klinger and Ebbesmeyer 2001). The fifth was conducted by Evans-Hamilton, Inc. as an outfall dispersion study (Ebbesmeyer et al 2002).

We divided the region into four quadrants, (A, B, C, D; Figure 4). The Western JF was defined as the region west of the sill that extends southward from Victoria, British Columbia. The Eastern JF is the region east of that sill.

Historical current meter data (Cannon this session) have shown that surface flow in the northern part of the Western JF (A) tends to move seaward, largely as a result of the Fraser River outflow. Surface flow in (B) also flows primarily seaward, but occasionally shifts landward due to periodic Pacific Ocean intrusions. The Eastern JF contains nine prominent tidal eddies (Ebbesmeyer et al 1991); thus a higher degree of particle retention was expected when compared to the Western JF, which has a higher degree of flushing. The Eastern JF was then separated into northern (C) and southern (D) sections to follow up the division evident upon initial inspection of the combined data sets (Figure 4).

To investigate whether or not these four quadrants function as semi-isolated hydrodynamic domains, releases from individual quadrants were examined and recovery percentages in all quadrants were determined.

Results

Cards originating from Quadrants A and B primarily travel out the Strait (Figs. 5 and 6). Material from Quadrant A was generally retained in A or transported to the outer coast and beyond (for the purpose of this paper, the outer coast is defined as the coastline from Alaska to the Columbia River). Material from Quadrant B also tended to move out of the

Strait, however, periodic flow reversals cause some proportion of surface-borne materials to be transported considerable distances inland (Figure 6). A substantial number of drift cards (33% of reports) from Quadrant B were deposited in the Victoria Bight and on Dungeness Spit, as well as in the San Juan Archipelago. Overall, recovery rates were substantially lower in these two quadrants compared with quadrants in Eastern JF. The largest percentage of cards was transported to the outer coast and beyond.

Quadrants C and D showed a high degree of particle retention and also the degree of highest linkage between quadrants. It was, however an asymmetric linkage. Particles from Quadrant C were predominantly retained within the immediate area, with a small percentage of material moving south to Quadrant D. Conversely, Quadrant D showed a high degree of retention, but also exported a relatively higher proportion of material to Quadrant C. Material from Quadrant D showed a slightly higher tendency to exit the Eastern JF and collect in Quadrants A and B and beyond.

Asymmetric linkages also were apparent between the Western and Eastern JF. Although Quadrant B periodically exhibited a tendency to transport material eastward, the Western JF showed a low degree of linkage with the Eastern JF. In contrast, the Eastern JF showed a stronger tendency to export material to the Western JF.

Table 1. Percent recoveries in each Quadrant.

Quadrant Released	Total Percentage of Cards Reported	Percentage of cards reported in A	Percentage of cards reported in B	Percentage of cards reported in C	Percentage of cards reported in D	Percentage of cards on the outer coast
A	7	29	5	7	5	54
B	8	20	4	26	7	43
C	34	1	2	84	12	2
D	31	5	3	17	70	5

Discussion

Surface particle retention and exchange within and between regions are factors important to MPA network design because they determine the contribution of locally-produced larvae to local and regional population persistence. However, while retention and linkage between sites is important for larval exchange, linkage can impose costs for locations affected by invasive species, oil spills and surface-borne pollutants.

The overall recovery rates provide evidence of flushing. Table 1 lists the recovery rates for each quadrant. Recovery rates in the Western JF (7.2; 7.8%) are four-fold less than those in the Eastern JF (33.5; 30.5%). This indicates for greater flushing in the Western versus Eastern JF.

This east-west asymmetry in flushing is reflected in the percentage of reports on the coast (Table 1). Cards from the well-flushed Western JF wind up on the outer coast as reflected by 43-54% of the reports there, whereas only 2-5% of the Eastern JF reports were from the outer coast.

In fact, the Western JF recovery rates are comparable to drift bottles released on the outer coast (Burt and Wyatt 1964). Of the 769 bottles released 80-120 miles from the Oregon coast, outer coast beachcombers reported 7% (Burt and Wyatt 1964). The Western JF is therefore flushed at rates comparable to those of the open coast.

Our results suggest that the Eastern and Western JF are semi-isolated from one another. Surface particles from the Western JF tend to move to the Pacific Ocean. This movement is asymmetric between northern and southern sides of the strait. The Eastern JF is more highly retentive than the Western JF. Within the Eastern JF (Quadrants C and D), retention is asymmetric, with the highest likelihood of retention in Quadrant C.

Recent studies have shown that regional drift card accumulations may not provide an accurate indication of site-specific larval recruitment (Klinger and Kido 2003). Even so, drift cards are effective tools for characterizing surface movement of particles and scales of linkage within and between regions. This information can be used to help guide MPA network design and other spatially-explicit management strategies. In addition, drift cards can be used to identify areas at risk for invasive species, oil spills, and surface-borne pollutants. In some cases, data resulting from drift card studies might be used to parameterize models of dispersion used in the development of conservation and management strategies (e.g., Largier 2003). A combination of approaches will be required to adequately describe regional oceanographic processes for the purposes of spatially-explicit management.

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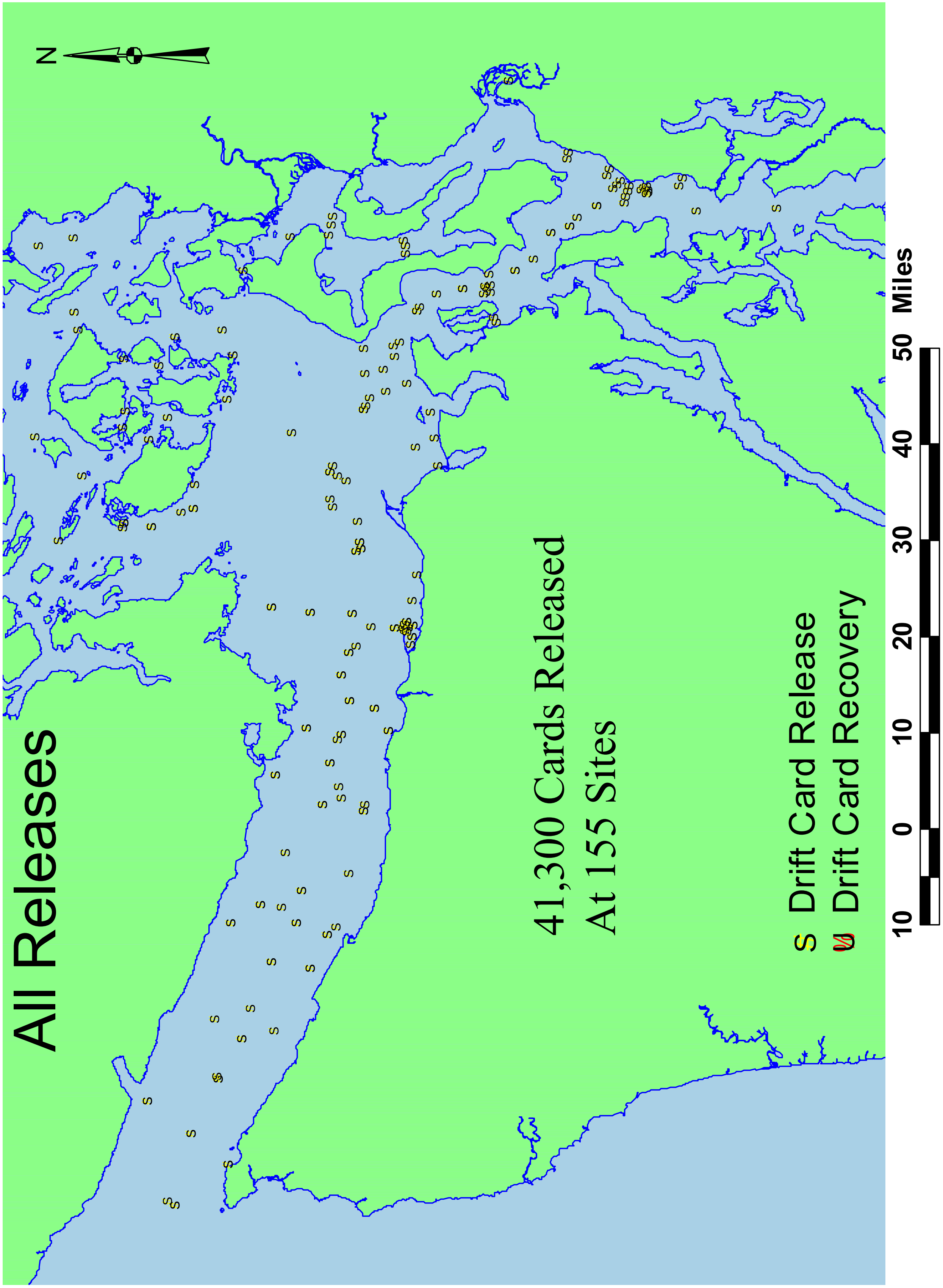

Figure 2. Locations of 155 drift card release sites.

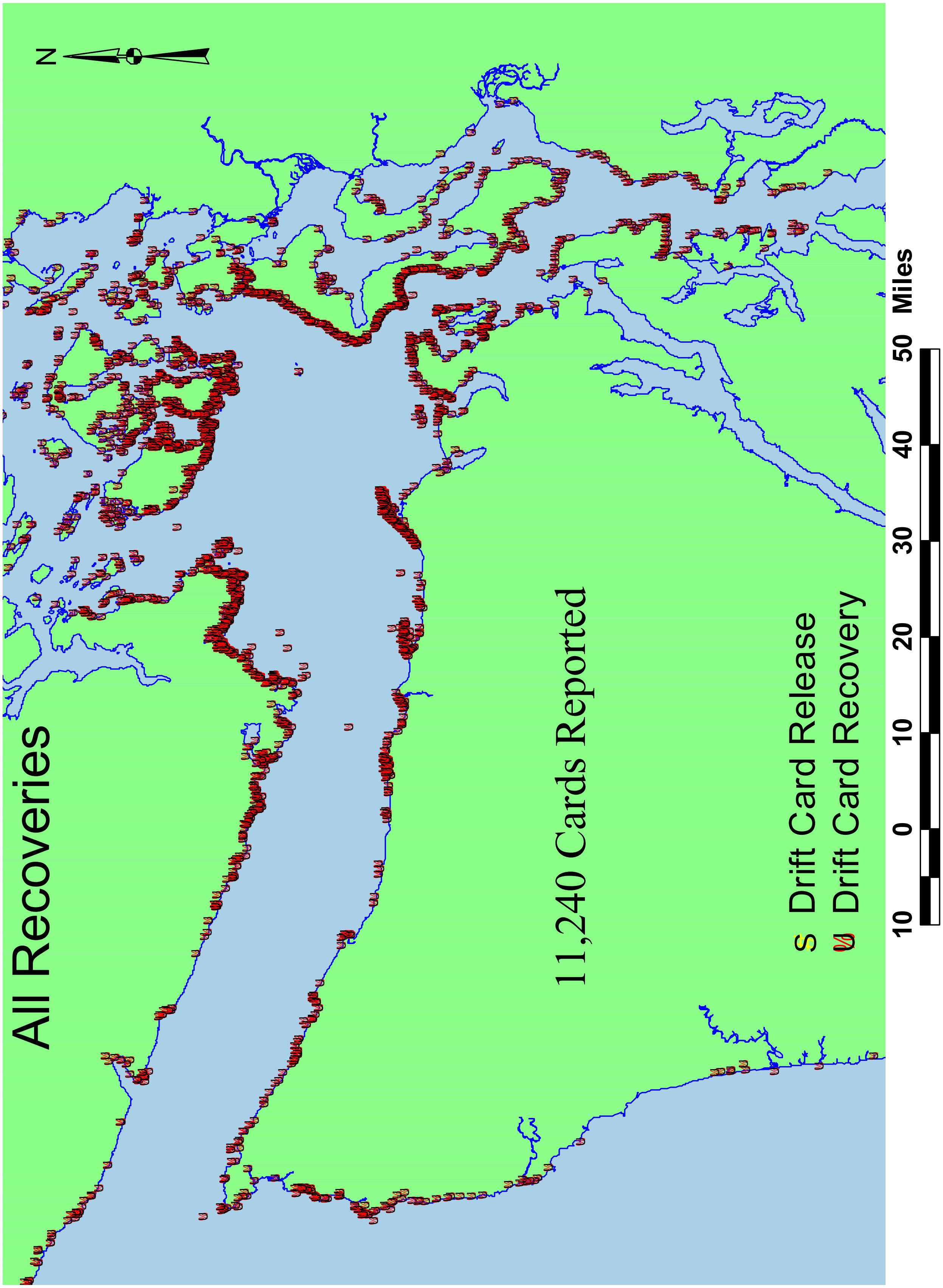

Figure 3. Locations of 11,240 cards reported.

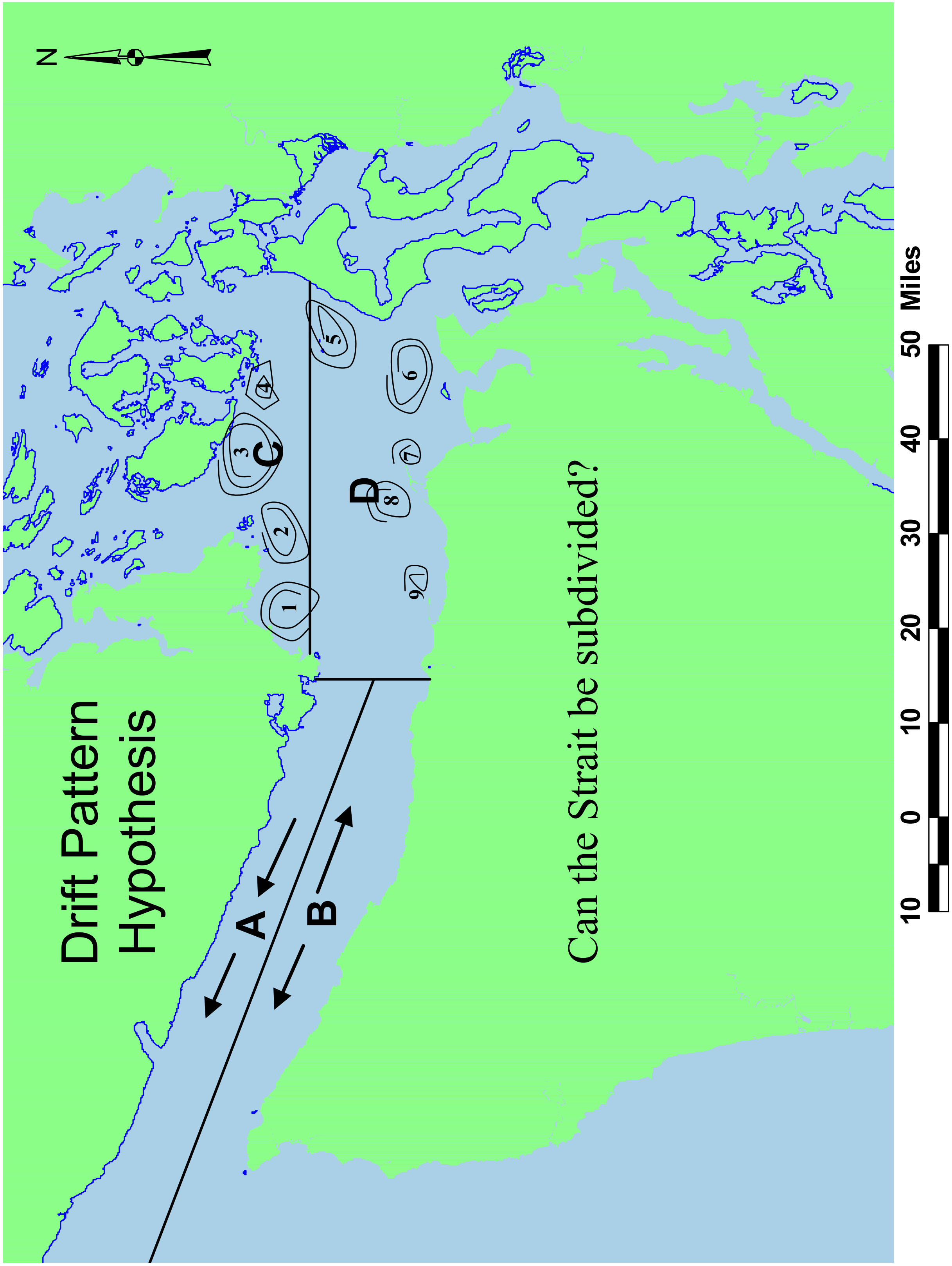

Figure 4. Layout of the four quadrants. General circulation patterns within Juan de Fuca Strait.

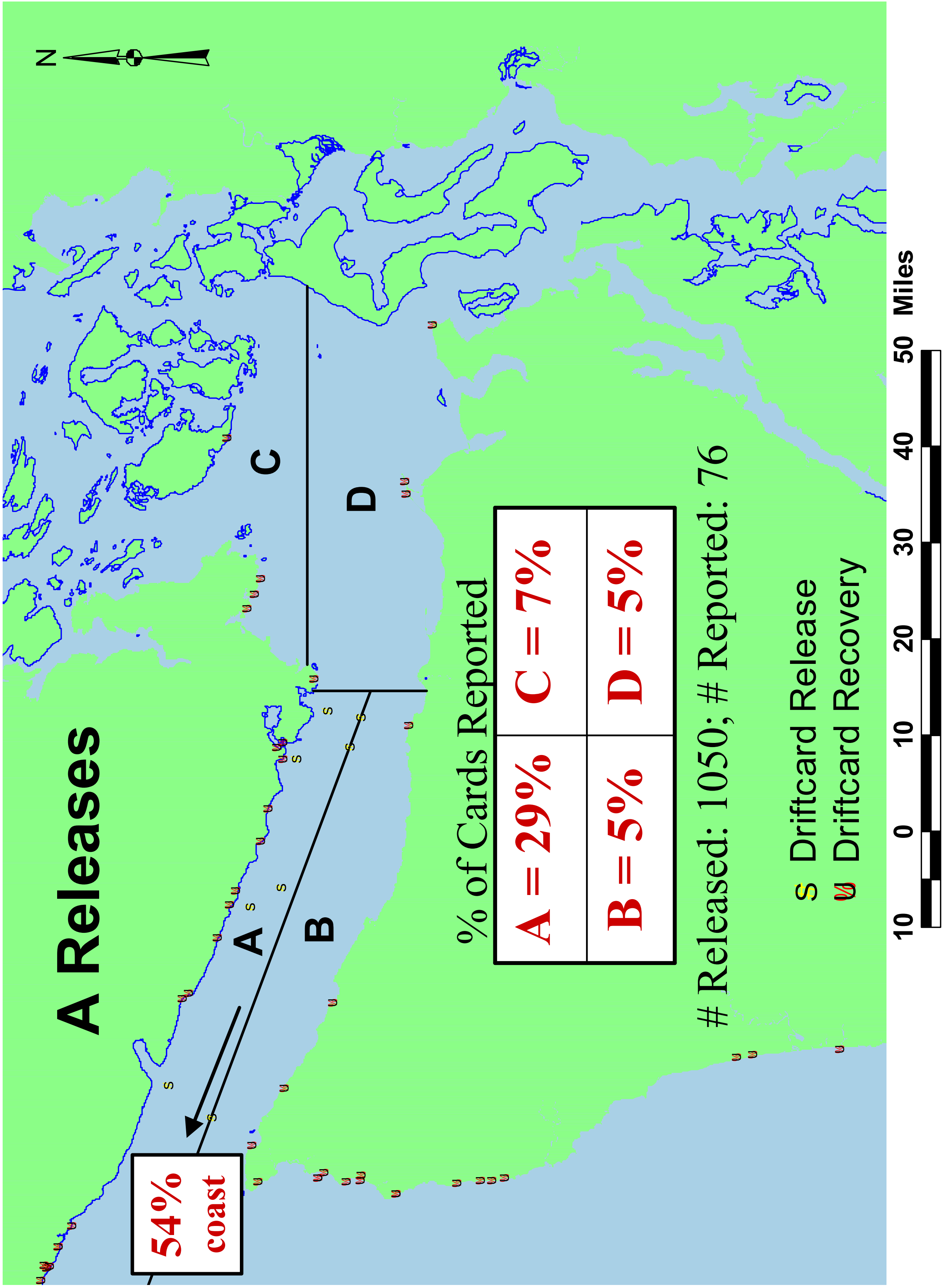

Figure 5. Recoveries of drift cards released in Quadrant A. For example, 7% of the cards reported were found in Quadrant C, and 54% were found on the outer coast.

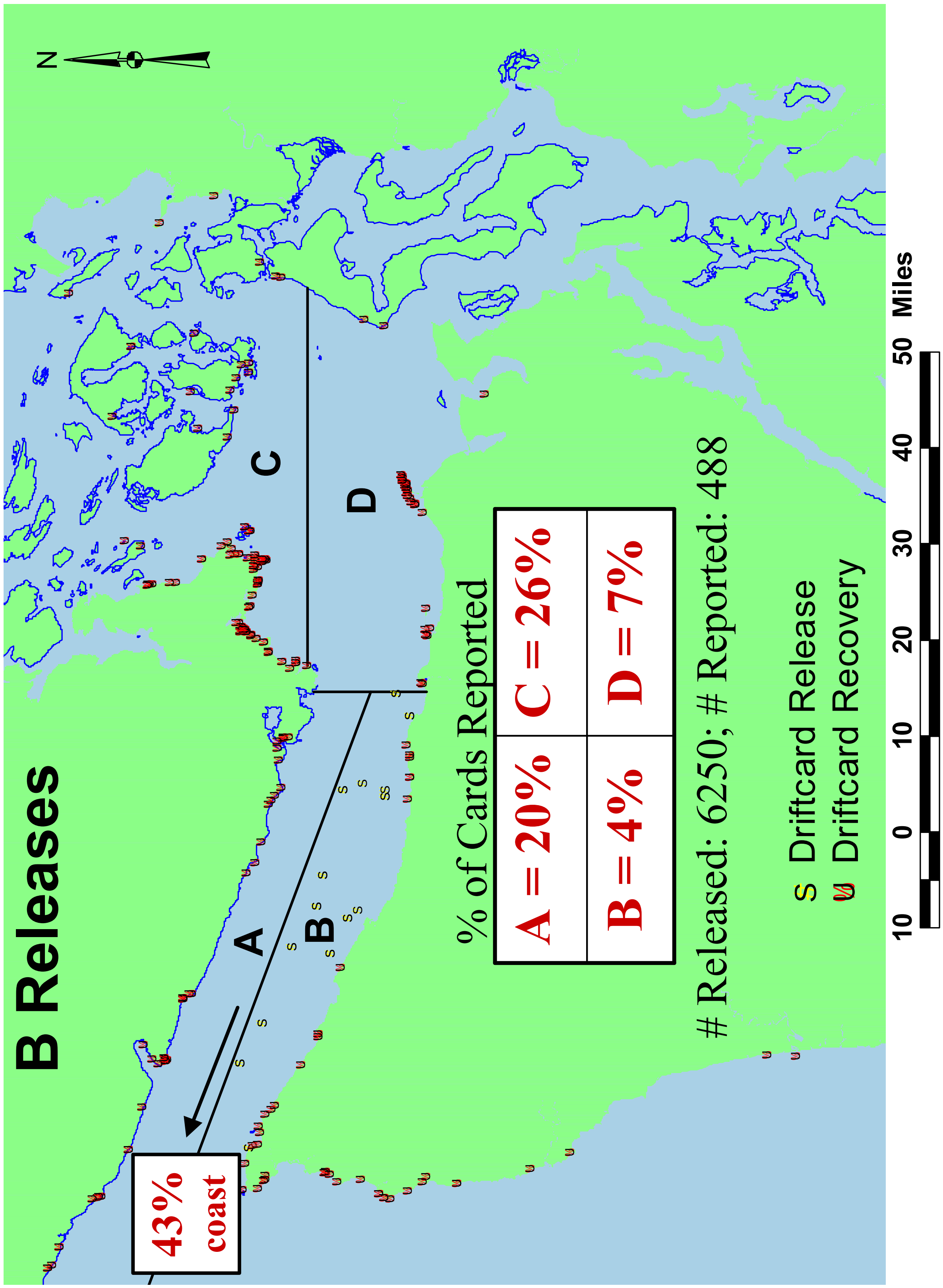

Figure 6. Recoveries of drift cards released in Quadrant B. For example, 26% of the cards reported were found in Quadrant C, and 43% were found on the outer coast.

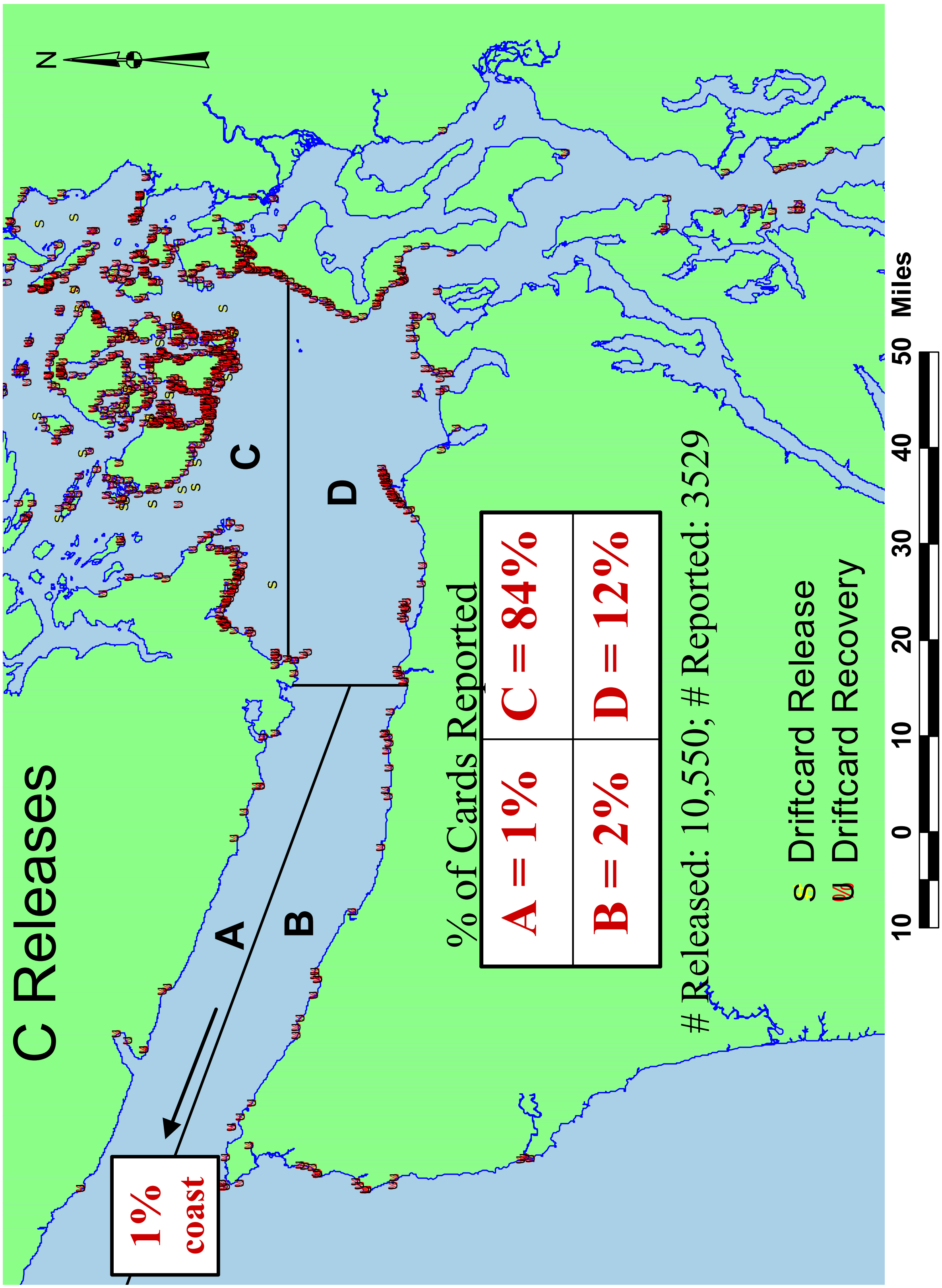

Figure 7. Recoveries of drift cards released in Quadrant C. For example, 84% of the cards reported were found in Quadrant C, and 1% was found on the outer coast.

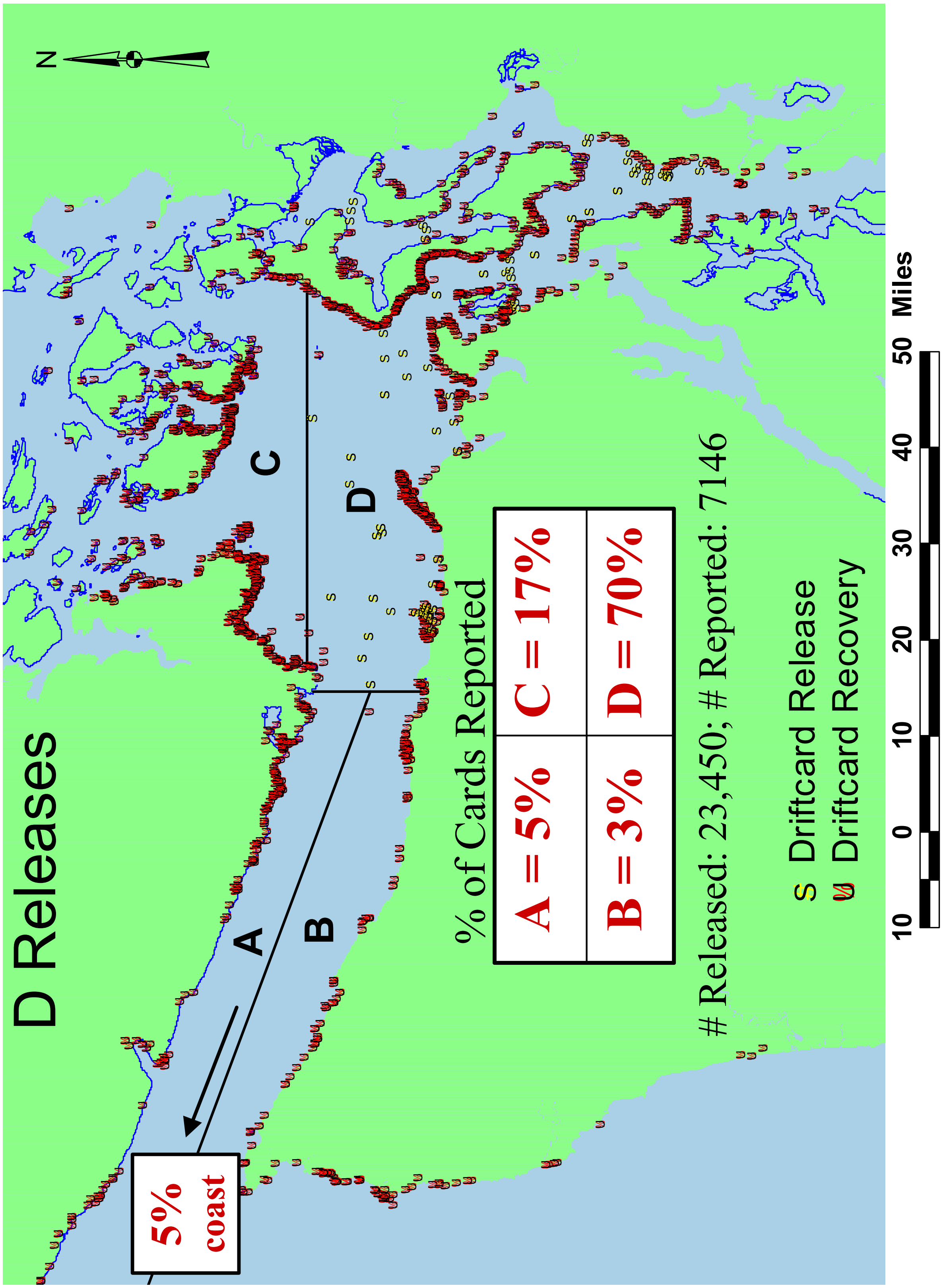

Figure 8. Recoveries of drift cards released in Quadrant D. For example, 17% of the cards reported were found in Quadrant C, and 5% were found on the outer coast.